"On the Spark Discharge from Metallic Poles in Water." By Sir NORMAN LOCKYER, K.C.B., F.R.S. Received January 31, —Read March 6, 1902.

[PLATE 3.]

During the appearance of the new star in the constellation Auriga, which was discovered in January, 1892, the Kensington photographs were the first* to show that several of the brighter lines were accom panied by absorption lines on their more refrangible sides.

This appearance I explained on the hypothesis that we were dealing with at least two bodies, one giving a radiation, and the other an absorption spectrum, the differential movements of which could be determined by the changes of wave-lengths observed.

In a paper† published in the year 1899, Dr. J. Wilsing made the suggestion that, in view of the great velocities shown by the large displacement of the lines in the spectra of new stars, and the occurrence of these displacements in the same direction, some other cause of them was probably at work, and he suggested that the cause might be high pressure, which drives the line towards the red.

The First Observations of Non-symmetrical Emission.

The non-symmetrical development of emission lines is of frequent occurrence in ordinary arc spectra. Typical photographs of such phenomena were referred to by me in illustration of papers communicated to the Royal Society more than a quarter of a century ago on peculiarities of emission and absorption spectra.‡

The following extracts from parts of these communications will serve to indicate the facts observed at that time :—

"*Photographs showing Non-symmetrical Lines.*

"I. Spectrum showing two Ag lines at about wave-lengths 4054·3 and 4210·0. Both lines are fluffy and reversed; the less refrangible line is much more strongly expanded on its more refrangible side, and is carried up to a much greater height as a radiation line than its other side. The more refrangible line is more symmetrical, but presents the same phenomenon to some extent, only in the opposite direction, its less refrangible side being the most developed.

"II. Spectrum of Rb, showing line at wave-length 4202. Here the two ends of the line are produced by radiation alone, the central

* 'Roy. Soc. Proc.,' vol. 50, p. 434.

† 'Astrophys. Journ.,' vol. 10, p. 113, 1899.

‡ 'Phil. Trans.,' vol. 164, Part II, pp. 805–813, 1874; 'Roy. Soc. Proc.,' vol. 28, pp. 428–432, 1879.

portion showing absorption on its more refrangible side, with fluffy shading on its less refrangible side."

Afterwards, when higher dispersions became available, the investigations of Messrs. Humphreys and Mohler on the effect of pressure on spectrum lines* showed that the actual wave-length of a line was increased by pressure; thus Humphreys† states "the wave-lengths of all fine and sharp lines, *and also of the reversals of heavy ones*, increase with increase of pressure around the arc, no matter how the lines may spread out, symmetrically or chiefly towards either side."

In the case of pressures of twelve atmospheres, a shift of scarcely 0·05 tenth metre was observed by Messrs. Humphreys and Mohler. Eder and Valenta‡ in their work on the spark spectra of argon and sulphur under pressure obtained a displacement amounting to as much as one tenth-metre. With flame spectra of the easily volatile metallic salts, small displacements, averaging 0·4 tenth metre, were observed by Ebert,§ and were explained by him as being due to an unsymmetrical broadening of the lines towards the red.

Dr. Wilsing thought that such investigations suggested|| "the direction which must be taken in the experiments for producing shifts of lines without motion in the sight line, and ultimately for producing double spectra."

Wishing to avoid the experimental difficulties necessarily connected with the employment of high pressures, he made use of the fact that very high tensions are produced when electric *sparks* are discharged in liquids.

He employed a large induction coil, with a spark gap inserted in the secondary circuit, in connection with a battery. With the passage of each spark "a blinding discharge took place between the electrodes in the water, giving a very intense continuous spectrum crossed by faint lines." The discharge spectra in water and air were photographed on the same plate with a spectrograph, the scale of the spectrum being about 50 mm. between λ 4800 and λ 4600, and the accuracy of the determination of the wave-lengths of the sharp lines could be obtained within a few hundredths of a tenth-metre. Further, several plates were employed which were secured with a grating spectrograph of high dispersion, and with a large prism spectrograph.

Dr. Wilsing investigated in this way the spectra of the metals iron, nickel, platinum, copper, tin, zinc, cadmium, lead, and silver, and arrived at the conclusion that "there now occur displacements of lines

* 'Astrophys. Journ.,' vol. 3, pp. 114–135, 1896; vol. 4, pp. 175–181, 249–262 (1896); vol. 6, pp. 169–232, 1897.

† 'Astrophys. Journ.,' vol. 6, p. 183.

‡ 'Denkschriften der K. akad. der Wiss. zu Wien.,' vol. 64, pp. 1–39, vol. 67, pp. 97–151.

§ 'Wied. Ann.,' vol. 34, pp. 34–90, 1888.

|| 'Astrophys. Journ.,' vol. 10, p. 115.

and double lines which are in every respect similar to those in the spectra of Nova Aurigæ." Pressure, then, according to Dr. Wilsing, is the cause of the duplication and broadening of the lines in the spectra of new stars.

The great importance of this result for stellar spectroscopy rendered it imperative to repeat the experiments, and I at once commenced them, using the large Spottiswoode coil, capable of giving a 42-inch spark in air, controlled by placing a large glass plate-condenser in the secondary circuit, so that a spark of length 3 mm. was obtained in air, and about 0·5 mm. in water. The photographs of the more intense lines in the water-spark spectrum showed very distinct reversals.

The work was postponed a little later owing to this coil being no longer available, but it was again resumed with a smaller (10-inch) coil while waiting for a new large one which is under construction.

With this coil the investigation has been extended by photographing the spark spectra of several other metals in water, and these have furnished material for a more general classification of the attendant phenomena.

The coil used for producing the discharge being capable of giving only a 10-inch spark, had a 1-gallon Leyden jar placed in parallel with the secondary circuit. The spectrograph employed was a large concave Rowland grating of 6 inches diameter, ruled with 14,438 lines to the inch, and having a radius of curvature of 21 feet 6 inches. The first-order spectrum was employed, arranged to photograph the region of the spectrum from λ 3800 to λ 4800, occupying a length of 18 inches on the plate. Distilled water was used in all cases.

Of the metals so far examined (iron, silver, lead, copper, zinc, and magnesium), only three—iron, zinc, and magnesium—show reversals of the principal lines, and those of zinc are very weak.

In all cases the lines of the spectrum of the spark in water are much broader than the corresponding lines in the spectrum of the air-spark. From an examination of the different photographs, however, showing many lines of varying degrees of intensity, it appears that the broadening is, for the most part, of a similar nature to that observed in the arc spectrum in air when an excess of material is introduced between the poles.

The Phenomena presented by the Spark in Water.

(a.) General.

In the cases of iron and magnesium, many lines undergo complete reversal, for example, the following :—

Iron.		Magnesium.
4045·98	4325·94	3829·50
4063·76	4383·72	3832·45
4071·91	4404·93	3838·44
4271·93	4415·29	
4308·06		

As shown by the enlargements, this reversal is not always symmetrical with the original bright line, and the part of the emission line on the red side of the reversal is the brighter. It will be evident that in such cases if the exposure is insufficient for the less intense component to be photographed, the appearance of a bright line in a position greatly displaced towards the red will be presented, as is shown in the line of iron at λ 4260·64.

In the case of copper, we have stopped apparently at such an intermediate stage, and the phenomena observed thus appear to agree more closely with those described by Dr. Wilsing. In this case no reversals have actually taken place, and the only lines seen in the water-spark spectrum present the appearance of broad bands, considerably displaced towards the red, and having their more refrangible edges rather sharply defined by absorption, which is not otherwise manifested, while the less refrangible edges are very diffuse.

With zinc two of the lines in the strong group of three in the blue-green region show reversal, the absorption line being nearly normal, separating parts of the emission line of very different intensities. These lines, λ 4722·34 and λ 4810·72, are much more intense on the red side of the central absorption line. In the remaining line of the triplet at λ 4680·32 there is no reversal, but the maximum of intensity of the emission line is also shifted towards the red.

(*b.*) *Classification of the Different Phenomena presented.*

Considering the photographs obtained with various exposures and conditions, the phenomena observed may be grouped as follows :—

(1.) Broadened bright line.
(2.) Broadened bright line with central absorption line.
(3.) Broadened bright line with non-symmetrical absorption (maximum of emission towards red).

(1.) *Broadened Bright Line.*—This appearance is well shown in the spectrum of copper and the under-exposed spectrum of iron.

The broadened line is not of uniform intensity throughout its breadth, being stronger on the blue side, which is terminated almost abruptly, while the broader towards the red is more diffuse.

(2.) *Broadened Bright Lines with Central Absorption.*—This is well shown in the central line of the violet triplet of iron at λ 4063·76.

(3.) *Broadened Bright Line with Non-symmetrical Absorption (Maximum of Emission towards Red).*—The best examples obtained of this type of reversal are in the spectra of iron. The strong line at λ 4260·64 in the water-spark shows the most decided asymmetry, the less refrangible component of the underlying bright line being 7 or 8 times stronger than the part on the violet side of the absorption line. There appears to be no suggestion, either, of the line being duplex, so that the asymmetery cannot be explained as due to the interaction of two neighbouring reversals of varying intensities.

In the case of the absence of any line at 4481·30 in the spark in water, it may not be owing to the balance of absorption and radiation, but to a special peculiarity of this line. From many considerations, I regard 4481·30 as a high temperature line only, and therefore it may be that the cooling action of the water envelope surrounding the water-spark entirely prevents the production of this radiation.

From these considerations it appears evident that, if proper exposures be given, lines may be photographed in the spectrum of iron, say, which show all the phenomena described by Dr. Wilsing, but so related to each other and the complete stage—that of reversal, symmetrical or unsymmetrical—that it is impossible to regard them as anything abnormal. A typical set of lines illustrating these points, beginning with complete reversal with maximum of emission towards red, is as follows:—

Type.	Example.	Remarks.
1. Complete reversal (strong)..	4415·29 (Fe)	Both components of bright line shown strongly, red side most prominent.
2. Complete reversal (weak) ..	4415·29 (Fe) (another photograph)	Both components of bright line shown, red side much the stronger.
3. Partial reversal (weak) ..	4282·57 (Fe)	Appearance of a bright line with a dark border on more refrangible side.
4. Partial reversal (weaker) ..	4282·57 (Fe) (another photograph)	Bright component predominant, dark line only just visible.
5. No reversal	4315·26 (Fe) and many other weak lines.	—

(*c*.) *Variation of Intensities.*

The most prominent lines in the water-spark are not always the chief lines of the air-spark. This is well shown in the spectra of iron and copper.

Many of the lines in the spark of iron, if their intensities are compared under the two conditions of sparking, show distinct inversions. A typical instance of this occurs with the lines at $\lambda\lambda$ 4422·74 and 4427·48. With the spark in air λ 4427·48 is quite twice as strong as λ 4422·74, whereas in the water-spark there is scarcely any trace of a line at λ 4427·48, the 4422·74 line being, however, easily seen.

Another example, slightly less prominent, is found in the lines at $\lambda\lambda$ 4315·26 and 4337·22. With the spark in air these lines are almost equal in intensity, but in the water-spark λ 4315·26 has about three times the intensity of λ 4337·22.

In the case of copper, in the ordinary spark the most prominent lines are those at λ 4275·32 and λ 4651·31. In the water-spark spectrum the line at λ 4587·19 is almost as strong as either of the lines just mentioned, although in the ordinary spark it is much weaker.

Application to Stellar Spectra.

I will next consider the bearing of these results on the explanation of certain features of the spectrum which is characteristic of new stars. It has been seen that in the water-spark the position of the absorption undergoes little if any change of position, while in the case of non-symmetrical reversals, a bright line may be observed greatly displaced towards the red. In the new stars, on the other hand, the absorption lines are greatly displaced, the accompanying bright lines occupying in comparison normal positions. The facts are as follows :—

In the case of Nova Aurigæ the emission lines had practically normal wave-lengths, but the displacements of the dark lines at H_ϵ was about 10·7 tenth-metres towards the violet, indicating a velocity of approach of about 500 miles per second.

The recent new star in Perseus exhibited the same normal positions of the bright lines, and indications of even greater displacements of the dark lines, at one time amounting to 15 tenth-metres at H_ϵ, representing a velocity of approach of the body producing the dark-line spectrum of over 700 miles per second.

These values differ enormously from those produced by pressure. The amount of shift produced by subjecting the light source to pressure is given by Humphreys and Mohler, in the paper above referred to, as follows :—

FIG. 1.

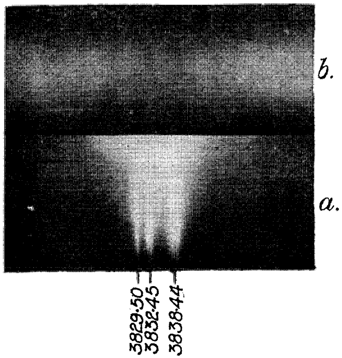
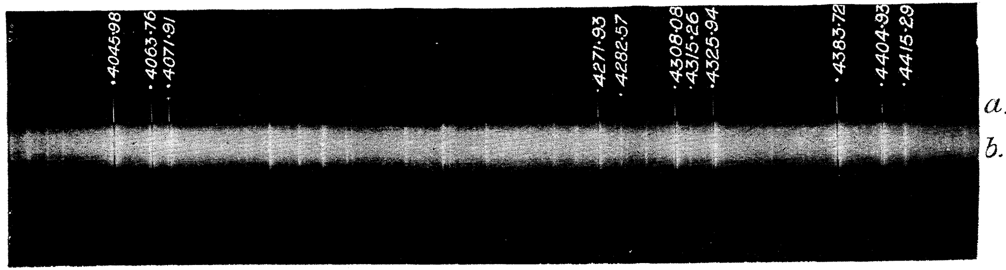


FIG. 2.



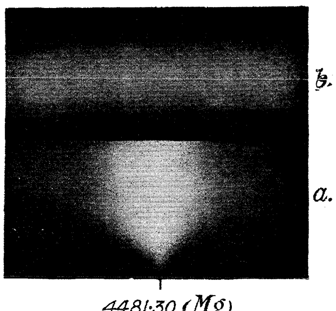


FIG. 3.

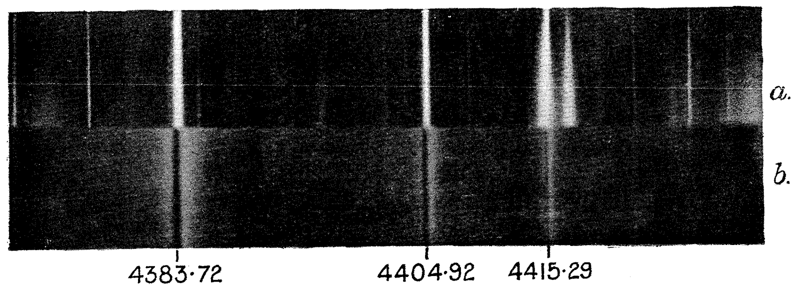


FIG. 4.

FIG. 1. Ultra-violet triplet of magnesium.
FIG. 3. Blue line of magnesium.

FIG. 2. Blue and violet lines of iron.
FIG. 4. Blue triplet of iron.

In all cases a = air spark, b = water spark.

λ	Shift in tenth-metres.	Atmospheres.
4045 ·98	0 ·009	6
4045 ·98	0 ·020	$11\frac{1}{4}$
4383 ·72	0 ·016	$9\frac{3}{4}$
4383 ·72	0 ·026	$11\frac{1}{2}$

We find then that the known direct effect of pressure on the radiation or absorption lines is the same, in quality, in water as in air, that is, we get displacements in the *opposite* direction to that we observe the dark lines to occupy in the spectra of Novæ, and we find further that the amount of shift observed in the spectra of new stars differs not only in this respect but also in degree, thus :—

Spark in water.	New stars.
1. Absorption lines least shifted.	Absorption lines most shifted.
2. Radiation lines most shifted.	Radiation lines least shifted.
3. Absorption shift small.	Absorption shift enormous.

It would thus appear that the pairs of bright and dark lines shown in the spectra of new stars do not arise from the cause which produces the appearances presented in the spectrum of the spark in water.

My thanks are due to Mr. C. P. Butler, who obtained and discussed the photographs of the spark spectra, and who, together with Dr. Lockyer, assisted me in the preparation of the paper, and to Mr. F. E. Baxandall, who checked the wave-lengths of the lines discussed and studied the behaviour of the lines representative of the different phenomena.

"The Differential Equations of Fresnel's Polarisation-vector, with an Extension to the Case of Active Media." By JAMES WALKER, M.A. Communicated by Professor CLIFTON, F.R.S. Received February 8,—Read March 6, 1902.

1. In many problems of physical optics it becomes necessary to know the differential equations that the polarisation-vector of a stream of light has to satisfy, and the boundary conditions that subsist at the interface of media possessing different optical properties.

FIG. 1.

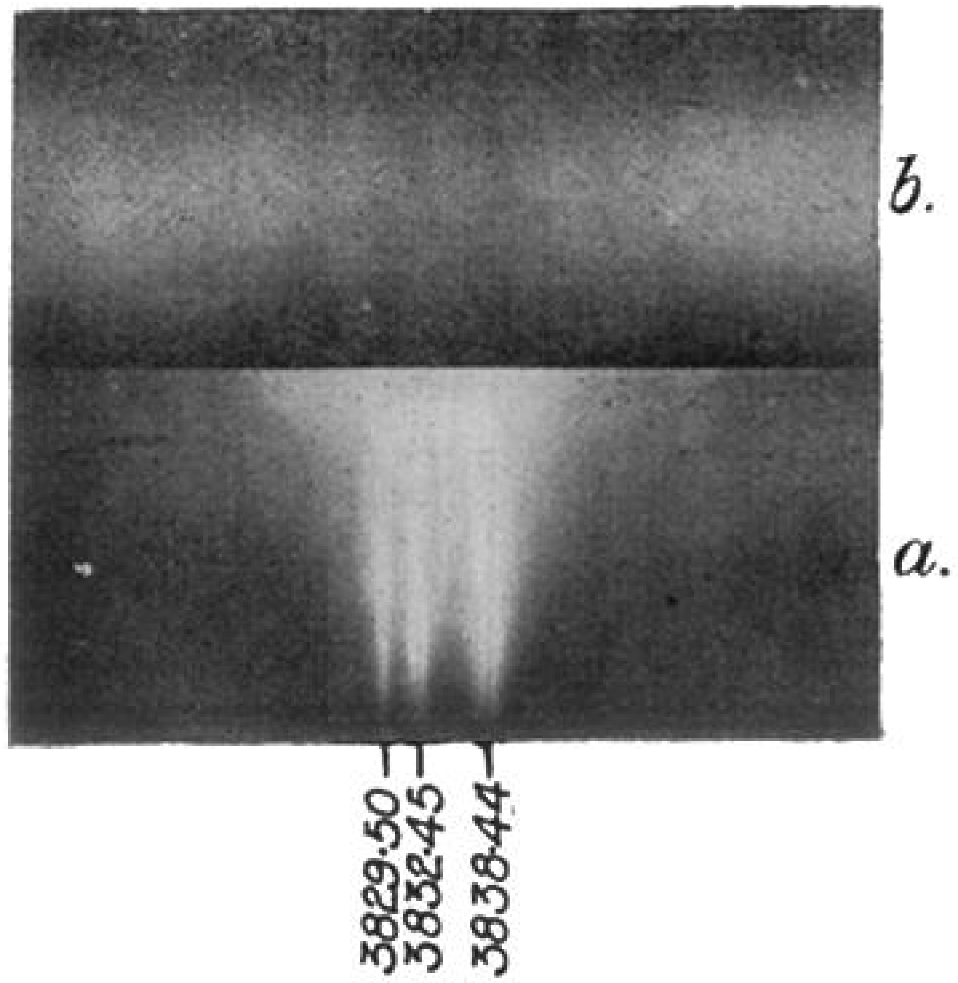
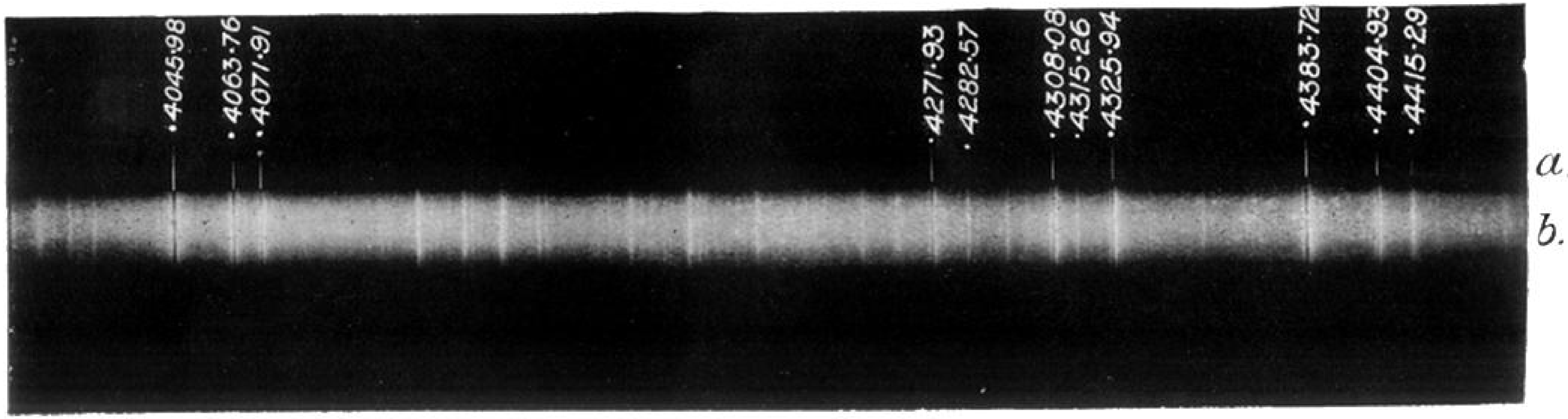


FIG. 2.



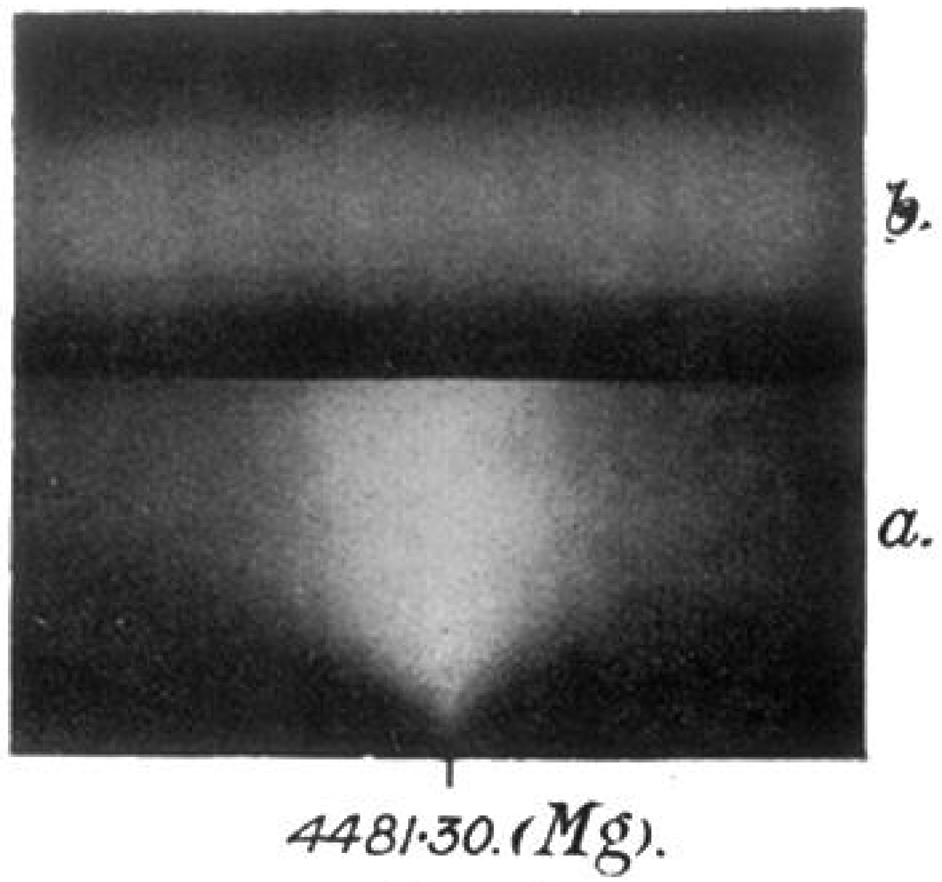
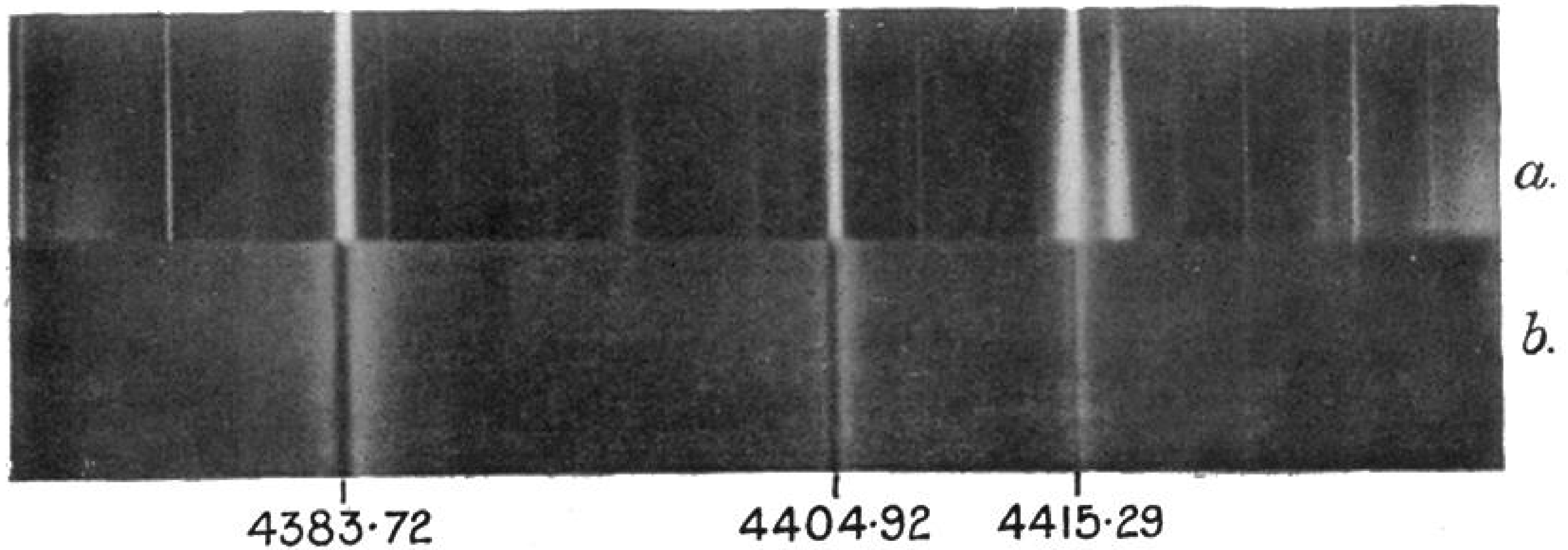


FIG. 3.



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